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Deriving an Implicational Universal in a Constrained OT Grammar

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This paper contains three major sections. In section 1, I describe an apparent typological universal concerning the scope of assimilation processes. In section 2, I demonstrate that the universal can be derived from the nature of a relatively simple OT grammar. In section 3, I discuss the problem of under and overgeneration in OT, including the counterfeeding problem, and constraints on the set of OT constraints. Section 4 contains a brief conclusion.

1. A Typological Universal[2]

The universal pattern I refer to has the form of an implicational hierarchy which can be intuitively grasped with a simple example. A language can have the alternations pn>mn and bn>mn, or pn>pn and bn>mn. That is if /p/ assimilates, then /b/ does too, but it could not be the case that pn>mn and bn>bn (i.e. pn>mn $\Rightarrow$ bn>mn). This claim is consistent with the evidence from Ancient Greek and Latin. In Latin both stops assimilate:

(1) Labials before /n/ in Latin

- b,p > m /_n (Labial, [-continuant] > [+voice], [+nasal], [+sonorant])

[1] I am grateful to participants in NELS 26 and the Tilburg Conference on the Derivational Residue in Phonology for helpful discussion. My thesis advisors Mark Hale and Höskuldur Thráinsson, as well as Morris Halle, Madelyn Kissock, Ida Toivonen and Andrea Calabrese have been discussing these ideas with me for over two years. I am responsible for all errors.

[2] Because of space limitations, this version does not include the a full discussion of the rule-based account of the universal which I discussed at NELS 26. However, in this section I will make use of basic concepts of rule-based phonology (e.g. assimilation and rule ordering) for expository purposes. See Reiss 1995 for a fuller discussion of the rule-based solution which appeals to the Subset Principle of acquisition. A third explanation, rooted in the phonetics of language transmission, is also plausible (cf. Hale (in press)).

/sop-/	sop-or 'deep sleep'	som-nus 'sleep'
/ab-/	Ab-ella (name of town)	am-nis 'stream, river'

In Ancient Greek, however, only the voiced labial /b/ assimilates to a following /n/, while the voiceless /p/ and voiceless aspirated /p^h/ do not:

(2) Labials before /n/ in Ancient Greek

- b > m / __ n (Labial, [+voice], [-continuant] > [+nasal], [+sonorant])

/seb-/	seb-omai	'feel awe'	sem-nos	'reverend, august'
/hup-/	hupnos	'sleep'		
/ap^h-/	ap^{h}neios	'wealthy'		

Two questions arise—1) why is /b/ the only labial stop to assimilate to /n/ in Greek, and 2) why can no language exist identical to Greek except that it had assimilation of /p/ > /m/ before /n/, but not of /b/? It seems intuitive that the answer to both questions lies in the fact that /b/ is 'closer' to /m/ than the voiceless stops are, since /b/ shares more features with /m/. In this section, I will formalize the notion of closeness in such a way as to allow us to answer these questions about Greek and to predict, in general, what factors might constrain assimilation processes universally.

Since assimilation rules are conceived of as spread of a single node in the feature tree, the alternation of oral and nasal consonants must actually consist of a two stage rule complex in some instances. The change of /b/ to [m] will merely require the spread of the specification [+nasal] from the /n/ to the labial, with concomitant delinking of the underlying [-nasal] specification.[3] However, the change of /p/ to [m] must involve changing the feature [voice] as well. The change of the two features cannot be expressed as a single process because the first node dominating [voice] and [nasal] is the root node, the spread of which implies complete assimilation, and that is not what we observe. This voicing of underlying /p/ can be accomplished in two ways—either by assimilation to the voicing of the nasal, i.e. by another spreading rule; or by a redundancy or repair rule guaranteeing that all nasals surface as voiced in Latin.

Note that it is possible to apply the rules in either order—nasalize both /p/ and /b/, then voice the voiceless nasal (given in (3a)); or voice the /p/, then nasalize underlying and derived /b/ (given in(3b)). In the Latin case the two orders produce indistinguishable output.

(3) Possible ordering of nasal spread and voicing in Latin

a.	/pn/	/bn/
nasalize labial stop	/m̥n/	/mn/
voice nasals	/mn/	—
output	[mn]	[mn]

b.	/pn/	/bn/
voice stops before nasals	/bn/	—
nasalize labial stops	/mn/	/mn/
output	[mn]	[mn]

[3] For the sake of simplicity I will ignore the automatic change of the feature [sonorant].

However, we can imagine a language with similar rules where the ordering would be crucial. If a language had a rule nasalizing only voiceless stops, followed by a rule voicing nasals (by either of the mechanisms described above) then we would expect to find cases of /pn/ > /mn/, but /bn/ > /bn/. Stated informally, /p/ could 'bypass' /b/ on the way to becoming [m].

(4) A hypothetical language—/p/ 'bypasses' /b/ on the way to [m]

input	/p-n/	/b-n/
nasalize voiceless stops voice nasals	/m̥n/ /mn/	— —
output	[mn]	[bn]

Note that we do know that nasalization can spread to voiceless stops, as in the voiceless nasals of the Welsh mutations (Clements and Halle 1983). Nonetheless, it appears that languages with derivations such as (4) do not occur, i.e. if a language exhibits the alternation *pn* > *mn* then it will also exhibit *bn* > *mn*.

In (5) I have sketched some other attested implicational hierarchies that fall into the same pattern as the Greek and Latin.

(5) Some more examples of implications

- If s>ʂ under some condition, then if the language has ʃ, it is also the case that ʃ>ʂ under the same conditions.
- If a language has alternations of the form *k* > *ŋ* / __*n*, then if the language has /g/, it is also the case that *g* > *ŋ* / __ *n* under the same conditions. If, on the other hand, we only have direct evidence that *g* > *ŋ* / __ *n*, it is not necessarily true that *k* > *ŋ* / __ *n* as well.
- If a language has alternations of the form *a* > *i* / __*i*, then if the language has /e/, it is also the case that *e* > *i* / __ *i* under the same conditions. If, on the other hand, we only have direct evidence that *e* > *i* / __ *i*, it is not necessarily true that *a* > *i* / __ *i* as well.
- If a language has alternations of the form $p > b^h$ / __ d^h, then if the language has a /b/ and a /p^h/, it is also the case that b, $p^h > b^h$ / __ d^h as well. On the other hand, if only one of the labials does not undergo the change, it must be *p*. (The diacritic ^{h} denotes [+spread glottis].)

Before attempting to explain the observed universal pattern we need to formulate precisely the general case. If we assume that all sounds are represented by feature trees, and here I will assume that these trees are fully specified, then let us define closeness as in (6).

(6) **Closeness**: If the set of identically valued nodes shared by the feature geometry trees representing *x* and *z* ($x \cap z$) is a proper subset of the set of nodes shared by the trees representing *y* and *z* ($y \cap z$), then *y* is **closer** to *z* than *x* is. We can denote this relationship as one of set containment: '*y* is closer to *z* than *x* is' means that $y \cap z \supset x \cap z$.
For example, *b* is closer to *m* than *p* is, using standard feature values. This can be seen by comparing shared valued features in (7).

North East Linguistics Society, Vol. 26 [1996], Art. 22

(7) Standard:/m/—candidates:/p,b/: /b/ is closer to /m/ than /p/ is

/p/	/b/		/m/
[-voice]	[+voice]		[+voice]
[-cont]	[-cont]		[-cont]
[-nasal]	[-nasal]		[+nasal]
[-son]	[-son]		[+son]

We can see in (8) that the closeness relation is not always defined. Neither of the candidates /p/ and /m/ is closer to /b/ than the other.

(8)Standard:/b/—candidates:/p,m/: Neither candidate is closer to the standard.

/p/	/m/		/b/
[-voice]	[+voice]		[+voice]
[-cont]	[-cont]		[-cont]
[-nasal]	[+nasal]		[-nasal]
[-son]	[+son]		[-son]

This example shows that mere feature counting is insufficient to determine relative closeness; a strict subset relationship is necessary.

With this definition of closeness we can now state the general form of the implicational hierarchies illustrated above.

(9) **Target-Output Closeness** (TOC): Suppose that in a language *L* there is a phonological process (a rule or set of rules) *P*, by which a segment *x* becomes *z*. If a segment *y* is closer to *z* than *x* is, *y* will also be a target of *P* in *L* and also become *z*.

The TOC can be seen to be consistent with the examples given so far: b⌒m ⊃ p⌒m, g⌒ŋ ⊃ k⌒ŋ, etc.

It is useful to distinguish the TOC from a similar principle which has been proposed in the literature, but which can be shown to have exceptions. The **principle of similarity**[4] basically claims that segments which share more features should assimilate more than segments sharing fewer. Note, however, that the voiced dental stop /d/ does not assimilate to a following /n/ in Greek, for example, in *hedna* 'bride price'. This may appear to contradict the TOC, but in fact it does not, since the TOC examines closeness to the *output* of an observed alternation to make predictions about potential assimilation in other feature complexes. A /d/ is clearly closer to /n/ than /b/ is. However, given a rule *b>m/__n*, the segment /d/ is not implicated as an additional target for assimilation if we follow the TOC algorithm established above in (9). Greater closeness to the rule trigger is not a sufficient condition for a TOC prediction, as shown by *hedna*. It is worth pointing out that geminate *nn* does surface in Greek forms like *ennea* 'nine'. If, on the other hand,

[4] Cf. Hutcheson 1973. Other relevant works are Cho 1989, Kenstowicz 1970, and Foley 1977.

/b/ not only nasalized, but also lost its place features in a hypothetical rule (*b*>*n*/ __ *n*), then the change would necessarily apply to /d/ as well, since /d/ is clearly closer to an output /n/ than /b/ is (bn>nn⊃dn>nn).

The Greek facts illustrate that closeness is not a trivial notion. It is not the case that the assimilation of target *x* to trigger *w* implies the assimilation of *y* to *w* whenever *y* is closer to *w* than *x* is. The TOC requires that an implied target be closer to the *output* of an observed target, not just closer to the trigger. It is sometimes necessary to stipulate that a target *x* have certain features which are in no obvious way related to the spreading features, as in this case of nasalization of /b/, but not of /d/ in Greek.

The TOC appears to be universally valid[5], and its validity is probably tacitly accepted by most phonologists. However, it is not obvious how to account for the TOC since it is trivial to write a grammar which contradicts it, as in (4). It seems unlikely and undesirable that closeness should be a primitive element of grammar. Stating a generalization such as the TOC as a global constraint which applies throughout the course of a derivation is undesirable because this requires that rules have the ability to look back or ahead to insure conformity with the predictions of closeness. As noted above, the TOC cannot reflect a simple constraint on the SD of rules because the nasalization of stops in Latin is actually a two step process. The constraint would have to require that voiceless stops alone not get nasalized if a later rule is going to voice them.

In Reiss (1995) I provide an account of this implicational universal in rule-based phonology. In brief, it appears to be unnecessary to posit the TOC as a principle of UG since it can be derived from simple, independently motivated principles of acquisition, especially the subset principle. The subset principle is based on the premise that children first create restricted grammars and expand their generative capacity upon exposure to positive evidence. For our purposes, we must determine how children go about constructing phonological rules without overapplying them. As illustrated above, a child learning Greek must not hypothesize that the presence of an alternation *bn>mn* in the primary linguistic data implies that all labial stops get nasalized before /n/, since /p/ does not. Similarly, the child must not hypothesize that all voiced stops get nasalized before /n/, since /d/ does not. The child must know that certain features of the target may be stipulated as prerequisites for the application of the rule. If this were not the case, the child might nasalize /p/ or /d/ before /n/ as well, and would require negative evidence to correct this overgeneralization. On account of space limitations, the details of this solution, which

[5] The only counterexamples I have come across are cases of total assimilation that can be analyzed as delinking of the root node and reassociation of the mora which had been associated with the delinked material. For example, sn> nn in Greek *hennumi* 'to put on clothing.' This should imply tn>nn and dn> nn by the TOC. However, if the only apparent counterexamples are cases of apparent total assimilation, then we may be justified in assuming that they are not assimilation at all. We probably do not want to treat deletion of a consonant with compensatory lengthening of the preceding vowel as assimilation either. I am currently investigating the implications of such counterexamples for OT (in which processes like assimilation have no status)—they may provide arguments for a necessary phonetic level within OT phonology.

derives the phonological universal from an extragrammatical source such as the subset principle, must be omitted from the present paper.

2. Implications in OT

I turn now to a discussion of Optimality Theory. McCarthy 1995 suggests that all OT constraints should fall into two classes:

(10) McCarthy 1995 on types of constraints

> Optimality Theory (Prince and Smolensky 1993) deals with constraints on surface forms. Yet it also depends crucially on constraints that regulate the **faithfulness** of the surface form to the lexical structure.

I now wish to demonstrate that a version of OT which makes use of only these two constraint types is able to generate the languages in (17) but cannot generate the impossible language sketched in (4). In other words, the TOC follows from the nature of an OT grammar which makes use of only well-formedness (w-f) constraints (constraints that refer only to output structure) and faithfulness or correspondence constraints (constraints that refer only to identity of features in morphologically related forms) in the sense that a grammar which contradicts the TOC is unstatable. This is clearly a good result for OT.

In (12)-(15) I list two faithfulness constraints and two w-f constraints which can be used to generate the relevant patterns. The actual formulation of the constraints is irrelevant, as long as the w-f constraints refer only to output strings. Faithfulness constraints have taken a variety of forms in the literature, including the suggestion that each one be divided in two. For example, Kiparsky (1995) has suggested having two faithfulness constraints for each feature, one referring to the feature regardless of value and one referring to the marked value only.

(11) Kiparsky's (1995) faithfulness constraints

a. Be faithful to underlying [F]

b. Be faithful to underlying [αF], where α is the marked value of [F]

Such suggestions do not appear to bear on the examples I will consider, except for an aspect of Kiparsky's proposal I will return to in section 3.

Following McCarthy and Prince (1994), we can call the constraint that favors faithfulness between input (UR) and output (optimal candidate) with respect to the feature [nasal] Feat_{IO}[nasal].

(12) [nasal] faithfulness—FEAT_{IO}[nasal]

> Correspondent segments in input and output must have identical values for the feature [nasal].

A constraint that favors faithfulness with respect to [voice] is FEAT_{IO}[voice].

(13) [voice] faithfulness—$FEAT_{IO}$[voice]

Correspondent segments in input and output must have identical values for the feature [voice].

The surface w-f constraints I adopt have the effect of demanding that adjacent segments share certain features. The constraint in (14) is a ban on sequences which agree in voicing, but not in nasality, which I will call 'voice link implies nasal link' (VOI/NAS).

(14) Voice link implies nasal link (VOI/NAS)

Adjacent segments which agree in voicing must agree in nasality.

To account for voicing assimilation between nasals and stops let's assume that the relevant condition is that adjacent non-continuants must share the same [voice] node.

(15) [-continuant] link implies [voice] link (-CON/VOI)

Adjacent non-continuants must agree in voicing.

Note that we will be able to use these two constraints to effect nasalization of a voiceless stop without positing a new constraint that demands that adjacent non-continuants agree in nasality. Adding this extra constraint will not effect the argument, so I will follow the more conservative approach.

It will prove useful to the following discussion to introduce the conventions and definitions given in (16).

(16) Some conventions and definitions

Suppose x,y,z. are distinct segments and F,G,H are features.

Definition: F(x) is the value which segment x has for feature F (+ or -).

Since the three segments are distinct, for any two segments x and y, there is always a feature F such that F(x) = -F(y).

Definition (equivalent to (6)): y is closer to z than x is iff

- F(x)= $-\alpha$ and F(y)=α and F(z)=α, that is -F(x)=F(y)=F(z) for some F (y and z agree with each other but not with x)
- and there is no G s.t. G(x)=β and G(y)= $-\beta$ and G(z)=β (there is no G such that x and z agree with each other but not with y)

For any feature, either all three segments agree, only x and y agree, or only y and z agree. It is never that case that x and z agree to the exclusion of y. The table below illustrates the three possible feature relations if y is closer to z than x is.

	x	y	z
F	+	-	-
G	+	+	+
H	+	+	-

I will now discuss how such a grammar can generate languages like (17abc).

(17) Treatments of /pn/ and /bn/
a) /pn/ > [pn] and /bn/ > [bn] (no assimilation)
b) /pn/ > [pn] and /bn/ > [mn] (assimilation of /b/ only)
c) /pn/ > [mn] and /bn/ > [mn] (assimilation of both)

Language (17a) is derived by ranking all faithfulness constraints above the relevant w-f constraints. Language (17c) is derived by ranking the w-f constraints above the faithfulness constraints. To derive language (17b) where only /bn/ undergoes assimilation, VOI/NAS and FEAT$_{IO}$[voice] must be ranked above FEAT$_{IO}$[nasal] and -CON-VOI. The ranking within pairs cannot be determined. The tableaux in (18) shows that there exists a set of rankings which generate the correct winning candidate for each input form.

(18) Language (17b)

/pn/	VOI/NAS	FEAT$_{IO}$[voice]	FEAT$_{IO}$[nasal]	-CON-VOI
☞[pn]	✓	✓	✓	*
[bn]	*!	*	✓	✓
[mn]	✓	*!	*!	✓

/bn/	VOI/NAS	FEAT$_{IO}$[voice]	FEAT$_{IO}$[nasal]	-CON-VOI
[pn]	✓	*!	✓	*
[bn]	*!	✓	✓	✓
☞[mn]	✓	✓	*	✓

We have accounted for all the languages in (17), but it appears impossible to write an OT grammar which will generate the pattern in (4), that is, one which will select [mn] as the optimal candidate for underlying /pn/ and also select [bn] as the optimal candidate for underlying /bn/. In other words, we cannot write the OT equivalent of the rule-based grammar in (4) whose output violates the TOC. This is clearly a desirable result for OT, since it means that it will not overgenerate in one respect.

Consider the string [mn] as a candidate for the UR /pn/. There are several possible rankings that will generate [mn] as the optimal candidate for /pn/, given in (19)—the two faithfulness constraints must be ranked lowest, and the other two constraints must be ranked highest. Ordering is not crucial among the pairs. Note that if either faithfulness constraint is ranked above one of the other two the candidate [mn] will not be chosen.

(19) To choose [mn] as optimal candidate for /pn/

/pn/	-CON/VOI	VOI/NAS	FEAT$_{IO}$[voice]	FEAT$_{IO}$[nasal]
[pn]	*!	✓	*	✓
[bn]	✓	*!	✓	✓
☞[mn]	✓	✓	*	*

However, note that none of the possible rankings represented in (19) selects [bn] as the optimal candidate for /bn/; they all select [mn] as optimal for the UR /bn/ as well. The impossibility of an OT version of grammar (4) is characterized as follows, where x=p, y=b and z=m:

(20) pn>mn bn>bn—Impossible language (4)

The first alternation (pn>mn) tells us that

i)respecting faithfulness to [-voice] is not as important as a w-f condition demanding that the labial be voiced (-CON/VOI >> FEAT$_{IO}$[voice]).

ii)respecting faithfulness to [-nasal] is less important than (lower ranked than) a w-f condition demanding that the labial be nasalized (VOI/NAS >> FEAT$_{IO}$[nasal]).

The second alternation (bn>bn) tells us that

iii)respecting faithfulness to [-nasal] is more important than (higher ranked than) a w-f condition demanding that the labial be nasalized (FEAT$_{IO}$[nasal] >> VOI/NAS)

But ii and iii are contradictory. They say **A>>B** and **B>>A**. Therefore they cannot both be true in a single grammar. Therefore the TOC follows from the nature of an OT grammar containing only these two types of constraint.

The proof in (21) demonstrates that the validity of the TOC is not dependent on the specific constraints invoked so far.

(21)General case for TOC

To prove: Using only w-f constraints and faithfulness constraints it can never be the case that /x/>[z] and /y/>[y] if y is closer to z than x is.

By the definition of closeness there exists features F and H such that F(x) = -F(z) and H(x) = -H(z). Therefore x>z means that F(x) > -F(x) and H(x) > -H(x).

So the w-f constraint C2 driving the change in F is ranked higher than faithfulness to the underlying value of F, C1. Claim i: **C2>>C1**.

And the w-f constraint C4 driving the change in H is ranked higher than faithfulness to the underlying value of H, C3. Claim ii: **C4>>C3**. (Note that it is possible that C2=C4).

However, y>y means that faithfulness to F, C1, outranks any w-f constraint that would change the value of F, including C2. Claim iii: **C1>>C2**.

And y>y also means that faithfulness to H, C3 outranks any w-f constraint that would change the value of H, including C4. Claim iv: **C3>>C4**.

But since claims i. and iii. are contradictory they cannot be in the same grammar. And since claims ii. and iv. are contradictory, they also cannot be in the same grammar.

So the surface forms of the language in (4) cannot be produced by an OT grammar using these constraints. It appears that changing the constraints will not allow a different result, as long as faithfulness to the UR is valued by some constraints, and there are no constraints which value just unfaithfulness to the UR—again, if we assume that all constraints are either faithfulness or surface w-f constraints.

The general form of the TOC in OT appears in (22) (in our example, x=p, y=b and z=m).

(22) The TOC in OT terms

Suppose that three segments x, y and z stand in the following closeness relationship: $y \cap z \supset x \cap z$ (y is closer to z than x is). If z is the optimal surface form of x, then z is also the optimal surface form of y in a given context.

It appears, then, that a language like that described by the ordered rules in (4) cannot be stated in OT terms, as long as there exist faithfulness constraints, and no unfaithfulness constraints other than w-f constraints.

3. Counterfeeding and constraining OT

I now turn to consideration of a class of chain shifts which can be captured in terms of closeness. For ease of exposition, I invoke forms containing the same segments as the Greek and Latin cases discussed above, but it should be clear that any set of segments will do, as long as the set relations of their feature specifications stand in a closeness relation.

Many languages show a patterns of 'stepwise' assimilation, exemplified by the following forms from the Italian dialect of Servigliano (Camilli 1929). Stepwise processes are chain-shifts of the form x>y and y>z, where y is closer to z than x is.

(23) Stepwise assimilation in Servigliano

a.	/lu patre/ > [lupatre] 'the father'	b.	/lu bardaššu/ > [lubardaššu] 'the boy'
	/un patre/ > [umbatre] 'a father		/un bardaššu / > [ummardaššu] 'a boy'.

The voiceless stop /p/ changes to the voiced stop [b] after a nasal, and the underlying voiced stop /b/ changes to a nasal after a nasal. (The original nasal also assimilates to the place of articulation of the following consonant. This change will not concern us.) In a system of ordered rules, it is clear that the change of voiced stop to nasal (/b/ > [m]) must precede the change of voiceless stop to voiced stop (/p/ > [b]). In other words, the rules are in a counterfeeding order. The two orders are shown in (3), without a formal statement of the relevant rules.

(24) Possible orderings of nasal spread and voicing in Servigliano

a. **correct order**	/np/	/nb/
nasalize voiced stop voice voiceless stop	-- /nb/	/nm/ --
output	[nb]	[nm]

b. **incorrect order**	/np/	/nb/
voice voiceless stop nasalize voiced stop	/nb/ /nm/	-- /nm/
output	*[nm]	[nm]

We have already shown that b is closer to m than p is.

Now consider the problem of generating the forms in (23) in an Optimality Theoretic grammar. Despite the fact that the segments appear in the opposite order here from the cases discussed above, we can use the same constraints as before, since it is their effect, rather than their exact formulation which is important. The fact that the sequence /nb/ surfaces as [nm] implies that VOI/NAS outranks faithfulness to the underlying value of [nasal].

So far we have two constraints and they must be ranked as in (25). Next consider the constraints needed to assure that the optimal candidate for the UR /np/ be [nb]. This requires that -CON-VOI outrank $FEAT_{IO}$[voice] as in (26).

(25) VOI/NAS >> $FEAT_{IO}$[nasal]

/nb/	VOI/NAS	$FEAT_{IO}$[nasal]
[nb]	*!	✓
☞[nm]	✓	*

(26) -CON/VOI and $FEAT_{IO}$[voice]

/np/	-CON/VOI	$FEAT_{IO}$[voice]
[np]	*!	✓
☞[nb]	✓	*

Now consider the relative ranking of the four constraints we have posited. There are twenty-four (4!) possible rankings of four constraints. However, we have already ruled out any ranking in which $FEAT_{IO}$[nasal] dominates VOI/NAS (half of all possible rankings), and we have also ruled out any ranking in which $FEAT_{IO}$[voice] dominates the constraint -CON/VOI (another half of the remaining rankings). This leaves us with only six remaining rankings available. We can see that only two patterns of assimilation are generated by these rankings. Either the optimal candidate for both sequences is [nm] (this is the mirror-image of the Latin case) or the optimal candidate for both candidates is [np] (which can be the winning candidate for /nb/ if VOI/NAS outranks faithfulness to voicing).

Another way to look at the impossibility of generating the Italian dialect data is the following. If the optimal candidate for the UR /np/ is [nb], and our OT grammar values faithfulness to the UR, then [nb] should also be the optimal candidate for the UR /nb/. On the other hand, if there exists a highly-ranked constraint that favors [nm] as the optimal output of /nb/ then the requirement that nasality spread outranks the requirement that output be faithful to the UR. If this is the case, then [nm] will also be the optimal output of the UR /np/.

(27) pn>bn bn>mn—Counterfeeding case like (23)

The first alternation (pn>bn) shows that

i) the w-f constraint requiring voice assimilation outranks faith to [-voice] (-CON/VOI >> $FEAT_{IO}$[voice])

ii) faith to [-nasal] outranks the w-f constraint requiring nasal assimilation. ($FEAT_{IO}$[nasal] >> VOI/NAS)

The second alternation (bn>mn) shows that

iii) the w-f constraint driving nasal assimilation outranks faith to [-nasal]. (VOI/NAS >> $FEAT_{IO}$[nasal])

But ii and iii are contradictory. They say **A>>B** and **B>>A**. Therefore they cannot both be true in a single grammar.

Again we can provide a general proof that applies to all chain shifts characterized by the closeness relation, not just our nasalization case but also, say, Welsh lenition (b>v and p>b).

(28) General case for counterfeeding

To prove: Using only w-f constraints and faithfulness constraints it can never be the case that /x/>[y] and /y/>[z] if y is closer to z than x is.

If y>z then there is a feature H such that $H(y) = \gamma$ and $H(z) = -\gamma$ (since y and z are distinct).

Therefore, the w-f constraint C2 demanding y>z demands /γH/>[-γH]. So this w-f constraint C2 must be ranked higher than a constraint demanding faithfulness to [γH], C1. Claim i: **C2>>C1**.

If x>y then there is a feature F such that $F(x) = \beta$ and $F(y) = -\beta$.

Therefore, the w-f constraint C4 demanding x>y demands βF> -βF.

and so C4 must be ranked above a constraint demanding faithfulness to [βF], C3. Claim ii: **C4>>C3**.

Since $H(y) = \gamma$, and $H(z) = -\gamma$, it follows that $H(x) = \gamma$. (**Otherwise y would not be closer to z than x is**.) The constraint ensuring that x does not surface as z demands faithfulness to [γH], C1. This constraint must be ranked higher than the w-f constraint demanding /γH/>[-γH], C2. Claim iii: **C1>>C2**.

But claims i and iii cannot both be true in a given grammar, and so the proof is complete.

We can now see that the exact formulation of the constraints is irrelevant as long as all the constraints fit into one of the two categories discussed above.

So we now have shown that a version of OT which is restricted to faithfulness constraints and w-f constraints fails to overgenerate in certain cases (it won't generate TOC violations), yet undergenerates in others (it won't get stepwise processes). The challenge now is to extend the class of constraints enough to get stepwise processes, but not so much that the TOC is lost.

A clear example of the wrong approach is to posit constraints such as "underlying /b/ surfaces as /m/" and "underlying /p/ surfaces as /b/" in a given context. Note that these are neither surface w-f nor simple faithfulness constraints. The problem with such an approach is two-fold. First of all, such constraints amount to nothing more than a restatement of the data. With such constraints any type of relationship between UR and surface form is possible: "underlying /p/ surfaces as [a]" would be a valid constraint. A related problem is that allowing the grammar such power would also remove our ability to account for what appear to be real constraints on output, such as the TOC. In other words, no principle would rule out a grammar with the constraints "underlying /pn/ surfaces as [mn]" and "underlying /bn/ surfaces as [bn]" which contradicts the TOC.

A more subtle example of a constraint that will lead to TOC violations is a context dependent faithfulness constraint. Such constraints can be stated in a variety of ways, two of which are given in (29).

(29) Undesirable constraints
a. If a candidate is faithful to the underlying value of [voice], then it should be faithful to the underlying value of [continuant] (This type of constraint can generate p>v and b>f!)
b. Voiced segments must be faithful to underlying [nasal]. (This constraint can be used to generate stepwise processes like the Servigliano p>b and b>m, but also p>m and b>b, which contradicts the TOC).

My argument to this point has been tacitly assuming that faithfulness constraints cannot be stated in the form of those in (29). Now, it is important to realize that surface w-f constraints are by their very nature context sensitive, as in (30).

(30) [+nasal] segments must be [+voice]—a context sensitive constraint.

Following a suggestion of Mark Hale (p.c.), I tentatively propose that the principle in (31) should be adopted so as to constrain OT grammars.

(31) Faithfulness constraints refer to single features.

If we do not accept (31) we will find that our OT grammar massively overgenerates in that it fails to conform to the TOC. Mark Hale has also pointed out that if it is correct, this condition raises a problem for Kiparsky's (1994) view of faithfulness constraints mentioned above. If, as Kiparsky proposes, faithfulness constraints can refer to marked values, then they are inherently context sensitive, since the marked value of a

North East Linguistics Society, Vol. 26 [1996], Art. 22

given feature is dependent on context. For example, [+voice] is marked in stops, but [-voice] is marked in sonorants.

I still have not dealt with the counterfeeding problem. The operation of constraint disjunction can produce counterfeeding results. Under disjunction we assume that candidates will not incur a violation of a complex constraint consisting of two simple constraints if they satisfy **at least one** of its component constraints (cf. Kirchner 1995[6]).

The complex constraint 'be faithful to at least one of [voice] or [continuant]' in (32), along with two w-f constraints favoring voiced segments and continuants, respectively, can generate a chainshift as shown in (33). For simplicity, I have chosen a chainshift of the form b>v and p>b (in an unspecified environment, say between vowels).

(32) Complex constraint

Be faithful to at least one of [voice] and [continuant]

(33) Chainshift using constraint disconjunction

/p/	*[-voice] /V__V	FEAT_{IO}[voice] OR FEAT_{IO}[cont]	*[-cont] /V__V
[p]	*!	✓	*
☞[b]	✓	✓	*
[v]	✓	*!	✓

/b/	*[-voice] /V__V	FEAT_{IO}[voice] OR FEAT_{IO}[cont]	*[-cont] /V__V
[p]	!*	*	*
[b]	✓	✓	!*
☞[v]	✓	✓	✓

These complex constraints are obviously very powerful. However they do allow us to generate the counterfeeding data and perhaps must be accepted as part of an OT which can account for well-attested processes. Fortunately, such disjunctive constraints appear not lead to TOC violations.

4. Conclusions

In conclusion, I would like to suggest that simple surface generalizations like the TOC can be extremely useful for studying the computational properties of grammars. This is because the definition of the TOC can be made explicit using basic logical notions like 'set containment'. The discussion of OT illustrates how we might narrow the search for necessary constraints on the set of constraints by explicitly characterizing upper and lower bounds on necessary generative capacity—we need enough power to get chains shifts, but not so much that we violate the TOC. If OT is to survive as a viable theory, it is necessary to limit its power in some principled fashion.

[6] Kirchner (1995) refers to the complex constraint as a conjunct constraint since it is only violated if both of its constituent constraints are violated.

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